

## Studies of the Effect of Comfort and Air Quality on Staff Productivity – The Indoor Health and Productivity Project

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## Indoor Health and Productivity Project

URL: <http://www.IHPCentral.org>

### Motivation

- Lack of credible and reliable information
- Wide gulf between research and practice
- Interpretation and generalization of a research project is a problem
  - Controlled experiment
  - Confounding variables
  - Lab vs. field setting
  - Underlying assumptions and limitations
- Policy issues, research questions, practical implications (standards, guidelines, best practices)



### Objectives

- Research and Policy Analysis
  - Critical reviews of existing IHP literature
  - Publication of summary articles in journals
  - Help formulate an IHP research agenda
  - Take advantage of cost effective opportunities to advance knowledge about means of improving IHP.
- Public Education and Information Dissemination
  - Development of an online bibliographic database (with abstracts) of IHP literature.
  - Highlight important research findings (both new and old)
  - Answer frequently asked questions (FAQ) on the topic of IHP



### Sponsors

- Subcommittee on Construction and Building (C&B)
  - Department of Energy
  - Environmental Protection Agency
  - National Institute of Standards & Technology (NIST)
- California Energy Commission
- Southern California Edison
- Potential Sponsors
  - Federal Energy Management Program
  - National Institute of Health
  - General Services Administration
  - State Energy Organizations
  - Private organizations interested in IHP related issues



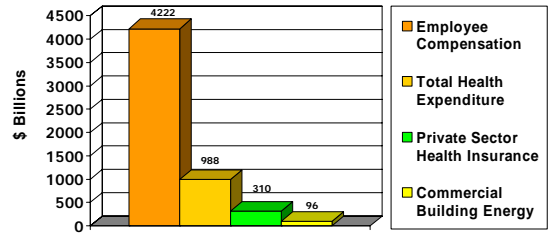
### Partners

- Current partners
  - National Research Council
  - University of California
  - Carnegie Mellon University
  - Harvard School of Public Health
- Potential partners in a broader coalition
  - Office Productivity Network, United Kingdom (<http://www.officeproductivity.co.uk/>)
  - International Facility Managers Association (IFMA)
  - National Research Council of Canada
  - Danish Building and Urban Research
  - Lighting Research Office, EPRI
  - Lighting Research Council, RPI



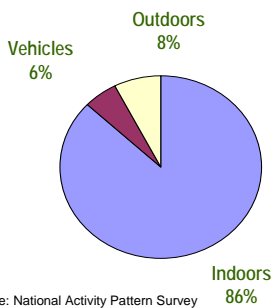
## Background

## U.S. Expenditures\*



\*Data from 1995 or 1996

## Time Budget for US Residents

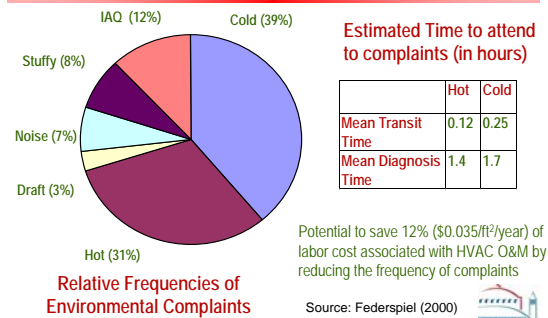


A typical pollutant release indoors is 1000 times as effective in causing human exposure as the same release in urban outdoor air\*

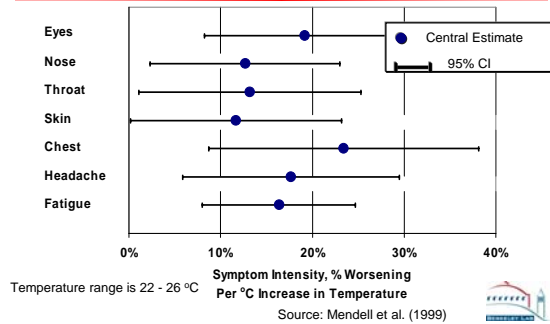
\* K R. Smith, Environment 30(8), 1988.

Source: National Activity Pattern Survey

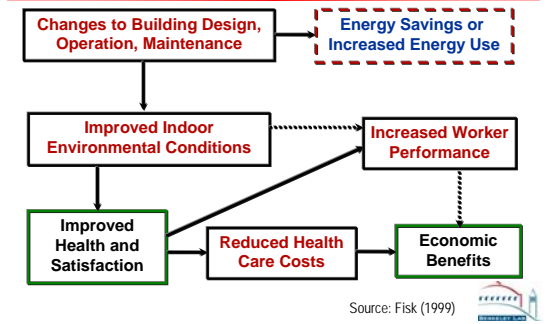
## Cost of Attending to Complaints



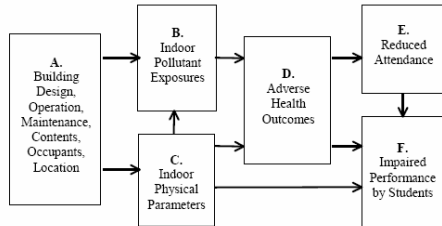
## Relationship of Temperature With SBS Symptom Severity in NIOSH/LBNL Healthy Building Intervention Study



## Impact of Energy Conservation Measures on IEQ and Energy Use



## Hypothesized Link Between IEQ and Student Performance



Source: Heath and Mendell (2002)

## Results from IHP Projects/Reviews

## Does Indoor Environment in Schools Influence Student Performance?

- Indoor environments in schools are of particular public concern because:
  - School buildings are more likely to have environmental deficiencies because of deferred maintenance policy
  - Children breathe higher volumes of air relative to their body weights and are actively growing; greater susceptibility to environmental pollutants than adults.
- Research suggests that student performance may be adversely affected by
  - low ventilation rate
  - less daylight or light

Source: Heath and Mendell (2002)

## Direct relationships between measured IEQ factors and performance.

PERFORMANCE OUTCOMES	STUDY FEATURES	MEASURED IEQ FACTORS		Reference
		POLLUTANT EXPOSURES AND CONTROL	PHYSICAL PARAMETERS	
	Setting/Subject	Microclimate Chemical Provides (outdoor source) Low Ventilation	Light Temperature Humidity Relative Humidity	
subjective mental performance +	S, C	C-S, E	↓	Sundin 1996
performance tests	L, A	E, E		Ono 1992
performance tests	L, A	E, E		McNave 1983
mathematics productivity	O, A	P, C, E		Baker 2001
reaction and performance tests +	S, C	Q-E, E	↓	Myrland 1994
unattended office tasks	O, L, C	E, E	↓	Wargocki 2000
learning efficiency	S, L, C	E, E	↓	Payler 1968
typing	L, C	E, E	↓	Wyon 1974
performance tests	L, C	E, E	↓	Wyon 1979

Source: Heath and Mendell (2002)

Assessed Relationships

- no statistically significant or noteworthy relationship
- statistically significant or noteworthy relationship with adverse outcome
- statistically significant or noteworthy relationship with beneficial outcome
- finding from study of strong design

## Direct relationships between IEQ related characteristics of buildings and performance.

PERFORMANCE OUTCOMES	STUDY FEATURES	IEQ-RELATED CHARACTERISTICS OF BUILDINGS				References
		Ventilation Features	Building Features	Interior Features	Daylighting	
	Setting/Subject	Air Conditioning	Room Facility	Newer Building	Daylighting	
achievement tests/academic progress +	S, C	PC, C-S, E				Heschong 1999
achievement tests	S, C	Q-E				McNall 1967
performance tests	S, L, C	E, E				Schore 1973
achievement tests +	S, C	C-S				Cobb 1993
unattended office work	O, A	Q-E, E				Korner 1994
achievement tests +	S, C	C-S				Lewis 2000
achievement tests +	S, C	C-S				Farman 1995
achievement tests +	S, C	C-S				Berney 1993
subjective mental performance +	S, C	C-S, E				Sundin 1996
reading comprehension	S, C	C-S				Hansen 2001
unattended office tasks	O, L, C	E, E				Wargocki 1999
unattended office tasks +	O, L, C	E, E				Lapin 2000
achievement tests	S, C	Q-E				Heschong 1999

Source: Heath and Mendell (2002)

Settings/Subject

S – school  
O – office or other non-school workplace  
L – laboratory  
C – children (<18 yrs)  
A – adults

Design

E – experiment  
Q-E – quasi-experiment  
PC – prospective cohort  
C-S – cross-sectional  
@ – controlled or adjusted for key potential confounders

## Impact of Daylighting on Students Learning

- Study:** 21000 students, 2000 classrooms in three school districts
- Focus:** Impact of daylighting in classrooms on students' learning
- Conclusions:** Daylighting helps improve standardized test scores of students by 15 – 26% in one of the school districts
- Major implications:** Design of adequately dimensioned and positioned windows and skylights, lighting control strategies
- Other Implications:** Test scores are driving school budget decisions; the study provides a compelling case for daylight classrooms to improve students' learning process

Source: Heschong (1999)

## Associations Between Classroom CO2 Concentrations and Student Attendance

- **Focus:** Exploring the association of student absence with measures of indoor minus outdoor CO2 concentrations (dCO2)
- **Dataset:** Absence and dCO2 data collected from:
  - 409 traditional and 25 portable classrooms
  - 14 schools in 6 school districts
  - Washington and Idaho
- **Variables included in Multivariate Modeling:**
  - Classroom attributes (HVAC systems)
  - Student attendance
  - School-level ethnicity, gender and socio-economic status

Source: Shendell et. al., 2003 (submitted to Indoor Air)



## Associations Between Classroom CO2 Concentrations and Student Attendance

- **Conclusions:**
  - 45% classrooms studied had short-term indoor CO2 concentrations above 1,000 ppm
  - A 1,000 ppm increase in dCO2 was associated with a 0.5 to 0.9% decrease in annual average daily attendance (ADA) = 10% to 20% increase in student absence
  - Outdoor air rates estimated from dCO2 and other collected data were not associated with absence
  - Annual ADA was 2% higher in traditional than in portable classrooms
- **Practical implications:** Study provides motivations for larger school studies investigating impact of dCO2 and accurately measured ventilation rates on student attendance/performance.

Source: Shendell et. al. (to be submitted to Indoor Air Journal)



## Estimates of Potential Health Benefits and Productivity Gains from Improved Indoor Environments

Source of Productivity Gain	Potential Annual Health Benefits in US	Potential U.S. Annual Savings or Productivity Gain (1996 \$U.S.)
Reduced respiratory disease	16 to 37 million avoided illnesses	\$6 - \$14 billion \$23 - \$54 per person
Reduced allergies and asthma	8% to 25% decrease in symptoms in 53 million allergy sufferers and 16 million asthmatics	\$1 - \$4 billion \$20 - \$80 per person (with allergies)
Reduced sick building syndrome symptoms	20% to 50% reduction in symptoms experienced frequently by ~ 15 million workers	\$10 - \$30 billion ~\$300 per office worker
Improved worker performance from changes in thermal environment and lighting	Not Applicable	\$20 to \$160 billion

Source: Fisk (2000)



## Some Health Effects Associated With Indoor Environments

Health Effect	U.S. Population Affected Annually
Lung Cancer Death from Radon	~ 13,000
Accidental CO Deaths	500-1000
Deaths from Environmental Tobacco Smoke	~45,000
Communicable Respiratory Disease	~260 million
Allergies	50 million
Asthma	16 million
Sick Building Symptoms (23% of office workers and teachers)	16 million



## Communicable Respiratory Disease

- Annual Economic Significance of Common Respiratory Illnesses\*
  - 180 million lost work days
  - 120 million additional days of restricted activity
  - Health care costs ~\$36 Billion (\$140/p.)
  - Total costs ~\$70 Billion (\$270/p.)

\*All estimates in 1996 US \$

Source: Fisk (2000)



## Health Benefits From Higher Ventilation Rate

- Study based on 3,720 employees in 40 buildings
- Sick leave data of office workers - metric to evaluate IEQ
- Association between ventilation rate, humidification and short-term sick leave
- 1.2 to 1.9 days of increased sick leave per person per year, depending on age and gender in spaces with lower ventilation rate

Source: Milton et al. (2000)



## Health Benefits From Higher Ventilation Rate

### Potential Economic Benefits of Increased Ventilation

Outcome	Annual Cost (Saving) per 100 Corporate Employees	Annual Cost (Saving) per 100 Full-time US Workers (1997 dollars)
Ventilation Costs	\$8,050	\$8,050
Sick Leave Costs	(\$48,000)	(\$24,444)
Net Savings	(\$39,950)	(\$16,394)

Annual savings: \$15.3 billion net  
Benefit to Cost Ratio: 3 (US) or 6 (Polaroid)

Source: Milton et al. (2000)



## Ventilation Rates and SBS Symptoms: Results of a Critical Review

- With Lower Vent. Rates
  - 20 of 27 studies found statistically significant increase in symptoms
  - 9 studies found >80% increase in prevalence of at least one symptom
- Potential Benefits of 5 L/s per person<sup>1</sup> increase
  - Most common SBS symptoms<sup>2</sup> decreased by ~40%
  - Roughly \$20 billion in associated productivity gains

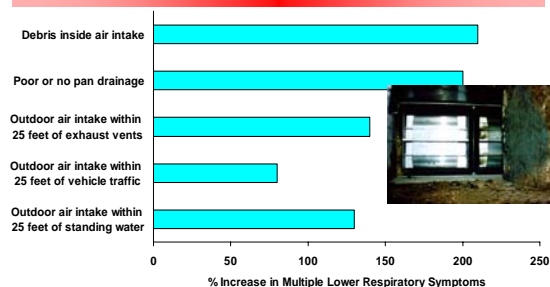
<sup>1</sup>50% of minimum ventilation rate standard

<sup>2</sup>Based on largest US study, 23% of office workers (15 million workers) affected frequently

Source: Seppanen et al. (1999)



## Association of HVAC Design & O&M with Health Outcomes



Source: Sieber et al. (1996)



## IHP Bibliography

- The largest publicly accessible online bibliography on this topic
  - Approx. 1,100 papers from major journals and conferences
  - Approx. 800 papers have online abstracts
  - User-friendly search engine
  - Available at [www.IHPCentral.org](http://www.IHPCentral.org)
- Updated every two years
- Great tool in conducting research on IHP



## IHP Bibliography - Browse

No.	Title	Publication Details	Authors	RefType
1	Passive Exposure to Tobacco Smoke: Hair Nicotine Levels in Preschool Children	Proceedings of Indoor Air '92, Volume 2, (2002), pp. 522-5		Proceedings
3	Fungal in Moisture-Damaged Building Materials	Proceedings of IAQ 91: Moisture, Mold, and Health Effects (IAQ and Moisture in Buildings (2001))	Hyvärinen A, Mäkelä T, Vepsäläinen A and Revellainen A	Proceedings
4	Measurements of Airborne Fungal and Endotoxin Levels in Water-Damaged Buildings	Proceedings of IAQ 91: Moisture, Mold, and Health Effects (IAQ and Moisture in Buildings (2001))	Tsai SM, Yang CS and Crandall MS	Proceedings
5	Outbreak of unexplained illness in a middle school—Washington, April, 1994	Morbidity and Mortality Weekly Report, Volume 45, Number 1 (Jan 1996), pp. 8-9		Newspaper Article
6	ACQEM position statement: Multiple chemical sensitivities, idiopathic environmental intolerance, College of Occupational and Environmental Medicine	Journal of Occupational and Environmental Medicine, Volume 41, Number 11 (Nov 1999), pp. 940-2		Journal Article



## IHP Bibliography - Search

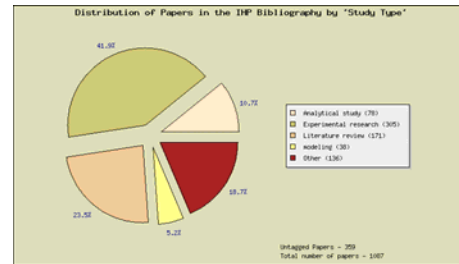


## IHP Bibliography - Details

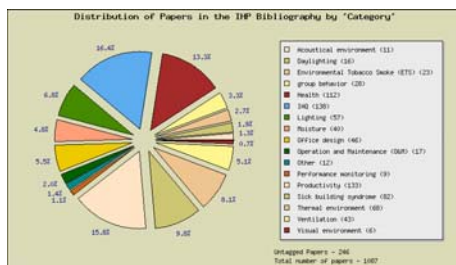
Details for Record # 176	
Reference Type	Journal Article
Authors	Fisk WJ, Rosenfeld A
Title	Estimates of Improved Productivity and Health from Better Indoor Environments
Category	Productivity
Study Type	Literature review
Keywords	acoustics, health, productivity
Abstract	<p>Theoretical considerations and empirical data suggest that acoustical technologies and practices can improve indoor environments in a manner that significantly increases productivity and health. The existing literature contains moderate to strong evidence that characteristics of buildings and indoor environments significantly influence rates of communicable respiratory illness, allergy and asthma symptoms, sick building syndrome, and worker performance. However, there is considerable uncertainty in the estimates of the magnitude of productivity gains that may be obtained by providing better indoor environments. The reported gains are very large. For the indoor spaces, the estimated potential annual savings and productivity gains are \$8 to \$14 billion from reduced respiratory disease, \$7 to \$8 billion from reduced allergies and asthma, \$10 to \$20 billion from reduced sick building syndrome symptoms, and \$25 to \$100 billion from decreased absenteeism in office personnel that are associated with health. Productivity gains that are quantified and demonstrated would serve as a strong stimulus for energy efficiency measures that continuously improve the indoor environment.</p>
Subject Size	
Publication Detail	Indoor Air Vol 7 (3), pp. 108-121
Online Access	<a href="http://journals.sagepub.com/abstract">journals.sagepub.com/abstract</a>



## Distribution of Papers by Study Type



## Distribution of Papers by Major Categories



## Major Accomplishments

- Developed a cost-effective approach to conduct quality research
- Developed an umbrella group for international collaboration and voluntary work in the field of IHP
- In some case, build on the existing research and enhanced the value of the work through supplemental research
- Consolidated previous fragmented efforts



## Associations or Causal Relationships?

### IEQ Measures

- Improve Thermal Comfort
- Higher Ventilation Rate
- Better Lighting Quality
- Incorporate Daylighting
- Improved HVAC O&M
- "Green" Materials & Furnishings



### Health/ Environmental Outcome

- Minimize Energy Use
- Improve Health
- Improve Worker Performance
- Access to Natural Environment
- Improved Personal Controls



## Future Directions

- Conduct more research to reduce uncertainties about the costs and benefits of specific measures.
- Help policy makers take effective public health actions based on scientific evidence and combining it with common sense.
- Conduct more research to provide justification for improving IEQ in schools and office environment.
- More closely explore the link between IEQ and energy consumption.



## Get Involved

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- IHP Project model pools funds to sponsor studies that address key research questions
- The model is very effective in getting big bang for your bucks
  - Help advance state of the art in IEQ
  - Help develop sound public policy and IEQ standards based on quality research



## Contact Information

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